Adv. Hort. Sci., 2016 30(3): 183-192 DOI: 10.13128/ahs-20281

Effect of pre- and postharvest salicylic acid treatment on quality characteristics of tomato during cold storage

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Key words: ascorbate peroxidase, decay, *Lycopersicon esculentum*, weight loss.

Abstract: Nowadays, there is a considerable tendency to replace dangerous chemicals with natural compounds, compatible with plant, human, and nature. This study was aimed to assess the effect of salicylic acid on quality and storage life of tomato (*Lycopersicon esculentum* cv. Baraka). The salicylic acid application was including plant foliar application three weeks before harvest at concentration 4 mM, followed by the postharvest dipping fruits in salicylic acid at different concentrations (1, 2, 4 mM), then storing at 10°C for 40 days to investigate quantitative and qualitative characteristics. The chilling injury symptoms, electrolyte leakage, decay and a* (redness) value significantly decreased and activity ascorbate peroxidase increased. Ascorbic acid content, total soluble solid, titratable acidity, firmness, and L* (lightness) retained by salicylic acid treatments. The salicylic acid application had no significant influence on weight loss and b*. Application of salicylic acid in all concentrations, especially a combination of treatments preharvest to concentrations 4 mM as well as postharvest 4 mM, had the highest influence on qualitative and quantitative characteristics and increased the postharvest life of the tomato fruit.

1. Introduction

Tomatoes are widely used, and those are a rich source of fiber, phenolics, vitamins A, C, and small amounts of vitamin E and lycopene. Lycopene prevents the harmful effects of free radicals and different types of cancers as well as cardiovascular disease (Pila *et al.*, 2010; Orabi *et al.*, 2015). Major problem of postharvest tomato is softening and ripening during storage, distribution, and marketing because of their susceptibility to damage (Batu, 2004; Agamy *et al.*, 2013). Fruit firmness and color are as effective factors of tomato quality, which are used as fruit quality indicator (Batu, 2004; Agamy *et al.*, 2013). Tomato is climacteric so its ripening continues after harvesting and it can become overripe quickly. Hence, its quality decreases and its shelf life limits (Batu, 2004). Pila *et al.* (2010) reported that owing to lack of information on appropriate postharvest treatments, packaging, temperature, etc., the fruits not only lose their quality but also encounter a substantial postharvest loss. Cold storage is one of the most efficient and most practical postharvest procedures that maintains quality of products from the harvest to consumption time (Bourne, 2006), and extending the storage life of fresh horticultural products, tomatoes can be stored successfully for weeks (Hatami *et al.*, 2013), but the main problem is the postharvest handling, because the tropical and subtropical products are sensitive to chilling injury (CI) (Soleimani Aghdam *et al.*, 2012). Hatami *et al.* (2013) reported that improper temperature management is the primary cause of many postharvest diseases and disorders. Elhadi and Jeffrey (2012) reported that mature green tomatoes are the most sensitive to low temperatures among the commercial fruit, and there is a risk to develop chilling injury if they are held below 13°C or 12.5°C (Rugkong, 2009) and 12°C (Galvez *et al.*, 2010; Zhang *et al.*, 2010). Sevillano *et al.* (2009) reported that chilling injury reduced tomato fruit quality. Commonly visible CI comprise several symptoms such as surface pitting (Soleimani Aghdam *et al.*, 2012) and alteration of ripening process as indicated by delayed or even total failure offruit color development and softening (Rugkong, 2009),

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Received for publication 21 April 2016
Accepted for publication 17 November 2016

increased susceptibility to Alternaria rot and decay (Ding *et al.*, 2002), decrease mealy texture when ripened (Alternaria and Cladosporium rots are usually associated with chilling injury) (Elhadi and Jeffrey, 2012). Salicylic acid (SA) is a phenolic compound and plant growth regulator (Zavala *et al.*, 2004) and defenses against biotic and abiotic environmental stresses. Plants produce reactive oxygen species (ROS) when exposed to biotic and abiotic environmental stresses conditions (Agamy *et al.*, 2013). ROS includes superoxide, hydrogen peroxide and hydroxyl ions (Dat *et al.*, 2000). Thus, ROS cause to damage in cellular structures. There is a mixture of non-enzymatic antioxidants (carotenoids, ascorbate) and enzymatic antioxidants in plants, such as catalase (CAT) and ascorbate peroxidase (APX) which inhibit harmful effects of these ROSs. The enzymatic action of APX reduces H_2O_2 using ascorbate as an electron donor (Orabi *et al.*, 2015). Salicylic acid is an antioxidant defense system and regulates different physiological and biochemical processes in plants including: plant growth (Khan *et al.*, 2003), stomatal conductivity (Hayat *et al.*, 2010), photosynthesis (Fariduddin *et al.*, 2003), seed germination (Babalar *et al.*, 2007), disease resistance (Janda *et al.*, 2007), heavy metal stress, low temperature, high temperature and salinity (Hayat *et al.*, 2008). Salicylic acid treatment could be used to enhance the chilling resistance of maize, cucumber and rice (Kang and Saltveit, 2002), pomegranate (Sayyari *et al.*, 2009) and tomato (Ding *et al.*, 2001, 2002). Salicylic acid delays the ripening of banana and kiwifruit during storage (Srivastava and Dwivedi, 2000; Zhang *et al.*, 2003). Babalar *et al.* (2007) reported that pre and postharvest SA treatments caused fruit quality maintenance in strawberry. Fattahi *et al.* (2010) reported that losses in fruit quality are mostly due to its relatively high metabolic activity during storage. Salicylic acid is known as a signal molecule in the induction of defense mechanisms in plants. Due to the risk of inappropriate use of substance chemicals in postharvest technology, it is essential to study the application of safe postharvest treatments along with cold storage. Since the time between tomato fruit harvest and consumption may take long weeks, and during this period many changes could happen that affect the postharvest behavior of fruits. Therefore, the aim of this article was to appraise the effects of pre and postharvest SA application to maintain the qualitative characteristics of tomato fruits at cold storage and increase the postharvest life of the tomato fruit.

2. Materials and Methods

Plant material and salicylic acid treatment

Fruits of tomato (Lycopersicon esculentum cv. Baraka) produced in the greenhouse at University of Hormozgan (Iran) were used. Baraka cultivar is a hybrid seed appropriates for the tropical region. Fruits were harvested at mature green stage in April 2014 and transferred to laboratory where they were selected for health and size, weight, and color uniformity. Fruits were divided randomly. Then, they were washed and dried in the air. Each treatment consisted of 60 fruits, and each treatment was composed of three replicates (20 fruit per replicate): three SA treatments were compared (4+1, 4+2, and 4+4 mM) consisting of a 4 mM SA plant foliar application three weeks before harvest followed by the postharvest fruit dipping for five minutes in SA solutions at different concentrations (1, 2, and 4 mM). Fruits harvested from non-treated plants were used as control. Tomatoes were stored at 10°C temperature and 85-90% relative humidity (RH) for 10, 20, 30 and 40 days (Hatami *et al.*, 2013). Samples were taken at every 10 days intervals during storage for quality evaluation.

Firmness and weight loss

Fruit firmness was measured using a penetrometer equipped with a 6 mm diameter flat probe exerting maximum force on fruit. Units were expressed as kg cm^{-2} (Shafiee *et al.*, 2010). Fruit weight loss was measured immediately after harvest and storage time. The results were calculated as percentage of weight loss at the start of the experiment and at different intervals during storage by this formula: %WL = [(W1-W2)/W1] × (100), where %WL= percentage weight loss, W1= initial fruit weight in (g), W2= final fruit weight in (g) (Zhang *et al.*, 2002).

Superficial color

Superficial color of tomato was measured using a Minolta chronometer model CR 400 and average readings at three points against each other in the fruits were recorded. Color indices inclusive (L*, a*, and b* values) were measured. Superficial color of the fruit was expressed as L* (the ratio of white to black color), a* (the ratio of red to green color) and b* (the ratio of yellow to blue color) (Shafiee *et al.*, 2007).

Chilling injury index (scores) and electrolyte leakage

Chilling injury index of fruits was evaluated at 10°C after 10, 20, 30 and 40 days in cold storage. Symptoms were manifested as surface pitting and

dehydration according to the method of Sayyari *et al.* (2009). The severity of the symptoms was assessed with scores according to the following 3 stage scale: 0 (no symptom), 1 (1-25% of damaged area), 2 (26-50% of damaged area) and 3 (>51% of the damaged area). The average extent of chilling-injury damage was expressed as a chilling-injury (CI) index, which was calculated using the following formula:

CI = [(value of hedonic scale) × (number of fruit with the corresponding scale number)] / (4 × total number of fruit in the sample).

The rate of electrolyte leakage (EL) was measured according to the method of Mirdehghan *et al.* (2007), using 6 discs (10 mm diameter) of peel tissue, cut with a cork borer. Conductivity was measured after 4 h of incubation in 25 mL of 0.4 M mannitol under constant shaking. The conductivity of the solution (L1) was measured with a conductivity meter (Ttracon WTW 325). After readings had been taken, the vials were autoclaved at 121°C for 15 min, and then cooled to 20°C. The conductivity of tissues (L2) was measured. Ion leakage was calculated as the ratio of L1 to L2.

Fruit decay index (scores)

Decay incidence of each fruit was determined by scores. According to the amount of the decay on fruit surface scales from 1 to 5 were given to the each treatment where; 1= normal (no decay on fruit surface), 2= trace (up to 5% of fruit surface were decayed), 3= slight (5-20% of fruit surface were decayed), 4= moderate (20-50% of fruit surface were decayed), and 5= severe (>50% of fruit surface were decayed). Results were expressed as fungal decay index (Babalar *et al.*, 2007).

Vitamin C (ascorbic acid)

Fruit vitamin C content was measured by using titrimetric method with the titration of filtrate against 2,6-dichlorophenol indophenol and the results of vitamin C content were expressed as mg/100 g (Pila *et al.*, 2010).

Titratable acidity and total soluble solids

Five ml of extracted fruit juice was diluted to 45 ml with distilled water. Then, extract fruit juice was titrated with 0.1 N sodium hydroxide to a pH of 8.1. Titratable acidity (TA) was determined as percentage of citric acid by this formula:

$$TA\ (\%) = [(V \times N \times meq)/Y] \times 100$$

where V= volume of sodium hydroxide used ml, N = sodium hydroxide normality, and meq = 0.064, Y = volume of bulk fruit juice ml (Saltveit, 2005). Total soluble solid (TSS) in the extracted fruits juice was measured with a portable refractometer (Model DBR95), and the results were expressed as Brix.

Ascorbate peroxidase

Ascorbate peroxidase (APX) was assayed by recording the decrease in optical density due to ascorbic acid at 290 nm for 1 min in a UV-vis spectrophotometer (model unicuv- 2100). Samples from pulp of 0.5 g fresh tissue homogenized and the homogenized samples were centrifuged at 14000 rpm for 15 min. The supernatant was used as crude enzyme extract for APX enzyme analyses. The 3 ml reaction mixture contained 50 mM potassium phosphate buffer (pH 7.0), 0.5 mM ascorbic acid, 0.1 mM EDTA, 0.1 mM H_2O_2, and 0.1 ml enzyme. The reaction started with adding of 0.1 mM hydrogen peroxide. The enzyme activity was calculated using the extinction coefficient 2.8 Mm^{-1} cm^{-1} for ascorbate (Nakano and Asada, 1981).

Statistical analysis

Statistical analysis was performed by SAS software (SAS Institute Inc., 1990) according to a split plot in time design on the basis of completely randomized design (CRD), with 3 SA concentration and 3 replicates. Data were analyzed by GLM and differences among means of data were compared by with Least Significant Difference (LSD) Test at a significance level of 0.05.

3. Results

Firmness and weight loss

The results showed a rapid decrease in firmness in the control set compared to the fruits treated with SA during storage, and all treated fruits were firmer than the control set ($P< 0.01$). Maximum fruit flesh firmness (3.2 kg cm^{-2}) was recorded in pre and postharvest SA treatments 4+4 mM and control set had the softest fruits (0.6 kg cm^{-2}) at the end of the experiment but, the difference was not statistically significant compared to the other SA concentrations (Table 1). No significant changes were observed in weight loss during storage for any treatments, with the exception of weight loss in 30 days SA-treated fruit, which was lower than the control set (Table 1).

Color assessment

The results of this investigation showed that pre and postharvest SA treatments had an effect on fruit lightness (L*) and redness (a*) value in comparison

Table 1 - Effect of pre and postharvest treatments salicylic acid in firmness, weight loss, L*, a*, b* of tomato fruit cv. Baraka and stored at 10°C for up to 40 days

Time storage (days)	Salicylic acid treatments	Firmness (kg cm^{-2})	weight loss (%)	Color parameter		
				L*	a*	b*
0	0	4.82±1.02 a	0.00±0.00 f	34.98±2.69 a	-6.13±0.63 g	15.47±1.17 e
10	0	3.38±0.18 cdef	1.62±0.82 e	29.37±1.23 fg	3.83±0.35 d	15.76±1.51 e
	4+1	4.11±0.07 abc	1.32±0.03 e	33.02±1.97 abc	-5.73±0.17 g	13.42±0.59 e
	4+2	4.18±0.03 abc	1.28±0.03 e	33.31±0.89 ab	-6.03±0.82 g	11.75±0.42 e
	4+4	4.29±0.021 ab	1.22±0.02 e	33.84±1.59 ab	-6.86±0.36 g	16.27±2.87 e
20	0	2.88±0.78 f	2.38±0.54 cd	26.62±0.80 hi	5.86±1.58 cd	24.59±2.97 d
	4+1	3.97±0.11 bcd	2.12±0.01 d	31.89±0.96 b-e	-4.94±0.59 fg	24.34±6.31 d
	4+2	4.08±0.08 abc	2.10±0.02 d	32.24±0.84 bcd	-2.45±0.37 ef	34.49±0.08 ab
	4+4	4.15±0.14 abc	2.09±0.01 d	32.46±1.00 bcd	-5.73±0.45 g	24.72±7.10 d
30	0	1.70±0.67 g	3.11±0.14 b	24.41±0.86 ij	11.84±2.14 b	32.06±1.73 bc
	4+1	3.64±0.07 b-f	2.69b±0.02 c	29.73±0.47 efg	-1.99±0.71 ef	31.89±0.99 bc
	4+2	3.75±0.07 b-e	2.66±0.03 c	30.16±0.95 d-g	2.94±0.11 d	28.14±4.10 cd
	4+4	3.78±0.09 b-e	2.65±0.03 c	30.67±0.52 c-f	-4.75±0.55 efg	27.53±9.01cd
40	0	0.60±0.10 h	3.92±0.62 a	22.60±1.07 j	19.87±1.85 a	31.34±3.77 bc
	4+1	3.02±0.08 ef	3.67±0.02 a	27.95±0.96 gh	5.64±0.33 cd	36.85±2.79 ab
	4+2	3.08±0.08 ef	3.64±0.04 a	28.21±0.16 fgh	5.54±0.38 cd	32.40±0.32 bc
	4+4	3.20±0.04 def	3.63±0.02 a	28.87±0.71 fgh	-1.70±0.70 e	39.76±0.70 a

Means within each column with different superscript letters are significantly different (p = 0.05) for each sampling.

with control set (P<0.01). No significant (b*) value were observed in treated fruits, except 20th days in 4+2 mM (34.49) and 40th days in 4+4 mM (39.76) SA-treated fruit, which were higher level than control set (31.34). During storage, the L* value decreased. The control set had the lowest L* value (22.60), and the highest value was recorded in pre and postharvest SA treatments 4+2-4+4 mM (28.21 and 28.87, respectively) at the end of the experiment, and their difference was not statistically significant compared to the other SA concentrations. Our results indicate that SA treatments delayed the loss of L* value in tomato during storage. In general, a* value increased during storage as well as ripening. In the other hand, the color development rate of tomatoes increased with the increase in maturation. The most value of color index a* with a negative value (-6.13) was recorded in the green fruits of the control set. The negative values were observed in immature fruits and treated fruits showed negative/lower a* values than control fruits. The highest value of color index a* (19.87) was recorded in completely ripened tomatoes of the control set at 40th days. The index a* had a sharp increase control set at 10th days with a* value changing from negative (green color) to positive (red color) (Table 1). Storing mature-green fruits, treated with salicylic acid at 10°C increased the postharvest life up to 40 days.

Chilling injury and electrolyte leakage

Our results showed that CI increased during storage, but applying different concentrations of SA could significantly (P<0.01) affect chilling injury index in tomato fruit. Salicylic acid treatments lowered the levels of chilling injury compared to that of the fruits of control set, and the highest chilling injury was observed in control set. No chilling injury symptoms were observed in tomato fruits with pre and postharvest treatments 4+4 mM (Table 2). The results obtained from the present study showed that electrolyte leakage of control set (70.27%) was significantly higher than that of SA-treated fruits end of the storage period, and there was no significant difference between concentrations used for treatment (P<0.01) (Table 2).

Fruit decay index

Decay increases during storage and the results of our evaluation showed that SA, at different concentrations, significantly affected fruits decay (P<0.01). Fruits with SA treatments showed lower levels of decay as compared to that of the fruits of control set. Highest decay was observed in our control set. In pre and postharvest treatments 4+4 mM, there were not any decay symptoms in tomato fruit after 40 days. We did not witness any significant differences between concentrations (4+1 and 4+2 mM) (Table 2).

Table 2 - Effect of pre and postharvest treatments of salicylic acid in chilling injury, electrolyte leakage, decay, ascorbic acid of tomato fruit cv. Baraka and stored at 10°C for up to 40 days

Time storage (days)	Salicylic acid treatments	Chilling injury	Electrolyte leakage (%)	Decay index	Ascorbic acid (mg/100 g)
0	0	0.00± 0.00 d	40.63±10.32 d	0.00±0.00 d	66±6.00 a
	0	0.00±0.00 d	56.59±4.05 c	0.00±0.00 d	32±1.05 f
10	4+1	0.00±0.00 d	26.21±1.81 gh	0.00±0.00 d	65±1.73 a
	4+2	0.00±0.00 d	24.39±0.74 h	0.00±0.00 d	66±3.00 a
	4+4	0.00±0.00 d	23.98±2.00 d	0.00±0.00 d	68±3.46 a
20	0	0.00±0.00 d	61.80±1.30 bc	0.00±0.00 d	18±3.00 g
	4+1	0.00±0.00 d	28.27±0.90 fgh	0.00±0.00 d	49±4.58 bcd
	4+2	0.00±0.00 d	25.63±0.65 gh	0.00±0.00 d	52±4.58 bc
	4+4	0.00±0.00 d	23.68±0.94 h	0.00±0.00 d	55±1.73 ab
30	0	0.60±0.20 b	65.11±5.47 ab	0.46±0.31 b	12±3.00 gh
	4+1	0.20±0.00 c	33.25±2.71 defg	0.20±0.00 c	44±4.58 de
	4+2	0.20±0.00 c	31.81±1.70 efgh	0.20±0.00 c	48±3.00 cd
	4+4	0.00±0.00 d	30.59±0.79 efgh	0.00±0.00 d	50±1.73 bcd
40	0	1.06±0.23 a	70.27±0.92 a	1.07±0.23 a	9±3.00 h
	4+1	0.33±0.12 c	37.53±1.21 de	0.40±0.20 b	39±3.00 e
	4+2	0.27±0.12 c	36.65±2.95 de	0.33±0.23 bc	41±3.46 e
	4+4	0.00±0.00 d	36.51±2.65 def	0.00±d	45±3.00 de

Means within each column with different superscript letters are significantly different (p = 0.05) for each sampling.

Vitamin C (ascorbic acid)

Tomato fruits vitamin C content was decreased during storage, and it was found to be maintained with pre and postharvest treatments of SA, and this result was statistically significant (P<0.01). Tomato fruits treated with SA showed comparatively higher levels of ascorbic acid than the fruits of control set (9 mg/100 g), and the highest ascorbic acid content in pre and postharvest treatments 4+4 mM (45 mg/100 g) was observed, but there was no significant difference between two concentrations of our treatment (Table 2).

Titratable acidity (TA) and total soluble solids (TSS)

Tomato fruits TA content was maintained with pre and postharvest treatments of SA, and it significantly resulted in firmer fruits comparing to the controls (P<0.01). Titratable acidity (TA) content in treated fruits was higher than the control set (0.86%), and our results showed that TA maintained with pre and postharvest treatments of SA and we observed the highest TA content in concentrations of 4+2-4+4 mM (1.02, 1.03%, respectively) at 40th days (Table 3). Also, TSS increased during storage. Highest and lowest TSS were observed in control set and treated fruits, respectively, and this difference was significant (P<0.01). SA application in this experiment had a significant effect on soluble solids. Therefore, soluble solids of control fruits (4.36 °Brix) were more than of treated fruits (2.70 °Brix in 4+4 mM) after 40th days storage (Table 3).

Ascorbate peroxidase (APX)

The results showed APX decreased in control fruits, it increased and then decreased again in treat-

Table 3 - Effect of pre and postharvest treatments SA in TA, TSS, APX of tomato fruit cv. Baraka and stored at 10°C for up to 40 days

Time storage (days)	SA treatments	TA (%)	TSS (°Brix)	APX (mg/g fw)
0	0	0.94±0.19 abcd	3.40±0.69 c	37.14±1.24 e
	0	0.92±0.01 bcd	3.43±0.15 bc	20.90±19.03 f
10	4+1	1.03±0.01 ab	2.23±0.15 d	54.78±1.12 ab
	4+2	1.04±0.01 ab	2.16±0.15 d	55.66±1.29 a
	4+4	1.04±0.02 ab	2.46±0.46 d	56.12±2.49 a
20	0	0.90±0.01 bcd	4.00±0.10 ab	18.80±11.17 f
	4+1	1.01±0.01 abc	2.66±0.12 d	52.31±2.06 abc
	4+2	1.04±0.01 ab	2.60±0.20 d	53.83±4.36 ab
	4+4	1.06±0.01 a	2.53±0.06 d	55.70±4.77 a
30	0	0.89±0.03 cd	4.26±0.21 a	7.38±2.89 g
	4+1	1.01±0.01 abc	2.66±0.06 d	40.18±2.47de
	4+2	1.02±0.01 abc	2.63±0.12 d	43.78±4.81 cde
	4+4	1.03±0.01 ab	2.66±0.06 d	46.42±3.11bcd
40	0	0.86±0.03 d	4.36±0.40 a	6.95±1.38 g
	4+1	1.00±0.01 abcd	2.63±0.12 d	38.06±1.09 de
	4+2	1.02±0.02 abc	2.66±0.0 6d	38.61±1.31 de
	4+4	1.03±0.02 ab	2.70±0.10 c	38.18±2.51 de

Means within each column with different superscript letters are significantly different (p=0.05) for each sampling.

ed fruits. The activity of APX in treated fruits was higher than the controls, and there was no significant difference between the three concentrations at the end of the experiment (P<0.01) (Table 3).

4. Discussion and Conclusions

The results of this study indicate that pre and postharvest treatment with SA produced the firmest fruits. Softening of fruits is one of the most common physical parameters to assess the progress of ripening (Srivastava and Dwivedi, 2000; Brummell, 2006) and softening is a major problem of tomato that limits the quality. Key factors associating with fruit softening are the depolymerisation and degradation of cell wall components (Brummell, 2006). Srivastava and Dwivedi (2000) reported polygalacturonase is primarily responsible for ripening associated pectin degradation and fruit softening. Level of polygalacturonase activity has been positively correlated with fruit ripening and softening in banana and tomato fruits. Application of salicylic acid is useful in inhibiting tissue softening in fruits by reducing cell wall hydrolases activities and maintaining cell membrane consistency (Supapvanich, 2015). Wei *et al.* (2011) reported that exogenous application of SA enhances defense mechanisms and production of antioxidants in fruits during storage that leads to a decrease in lipid peroxidation of the cell membrane and results in maintained cell membrane structure. This result was in agreement with the reports of Babalar *et al.* (2007) and Shafiee *et al*. (2010) that suggested pre and postharvest application of SA on strawberry could decrease the softening and keep them firm during storage. Zhang *et al.* (2003) showed that SA effectively prevented kiwifruit softening during storage and rate of fruit ripening related to internal SA concentration as well as Srivastava and Dwivedi (2000) reported that salicylic acid treatment inhibited the process of banana fruit softening during ripening. Srivastava and Dwivedi (2000), Zhang *et al.* (2003) and Wang *et al.* (2006) reported that rapid softening of fruits during ripening was simultaneous with rapid decrease in endogenous SA of fruits. Tomato fruit weight loss did not show changes in response to SA treatments (except in 30th days lower than the control set). The results of this study did not accord with the ones of Babalar *et al.* (2007) and Shafiee *et al.* (2010).

The L* value decreased during storage. Babalar *et al*. (2007) reported higher lightness in pre and postharvest SA treated strawberry fruits than control. Shafiee *et al.* (2010) showed SA treatments were not effective on fruit lightness in comparison with the control set. Fattahi *et al.* (2010) suggested that the decrease in L* value represented the formation of dark color in the pulp due to oxidative browning reactions or increasing in brown pigment concentrations. Value a* increased during fruit ripening. The same results were obtained from pre and postharvest SA application on strawberry (Babalar *et al.*, 2007), but Shafiee *et al.* (2010) reported that SA treatments were not effective on a* value in comparison with control. The a* value is a useful index of maturation and the degree of ripening in tomato (Artes *et al.*, 1999) and the external color is a key factor indicating the quality of tomato (Supapvanich, 2015). Changes in a* result increase the respiration rate during storage. The salicylic acid treatment causes a decrease in respiration and a delay in the appearance of the climacteric peak, which is concentration-dependent (Srivastava and Dwivedi, 2000). Shafiee *et al.* (2010) reported that the effect of SA treatments might be due to the reduction of respiration, and it prevents from an increase in a* value, so it could have an advantage in delaying the senescence. The SA application did not affect b* value except 20th days in 4+2 mM and 40th days in 4+4 mM SA-treated fruit, which showed higher level than control set. There were not literature about the effect of pre and postharvest application of SA on b*changes.

Salicylic acid treatments lowered the levels of chilling injury compared to that of the fruits of control set, and the highest chilling injury was observed in control set. Ding *et al.* (2001, 2002) reported that chilling injury was manifested in tomato fruit by some symptoms. Severely injured fruit developed sunken areas (blemishes) an increased susceptibility to Alternaria rot and decay. Initially, CI affects the cell membrane with changes in the fatty acid of phospholipids. Secondary damages are on the cell membrane that leads to disruption of the cell structure (Soleimani Aghdam *et al.*, 2012). Asghari and Soleimani Aghdam (2010) suggested that treatment with SA prior to low-temperature storage induce heat shock proteins (HSPs) biosynthesis and, at the same time, CI tolerance in tomatoes and peaches. Accumulation of the heat shock proteins (HSPs) in chilling-sensitive horticultural products with SA treatments would allow their storage at low temperatures without CI development. This membrane damage can be measured by the electrolyte leakage, which the results obtained from the present study showed that electrolyte leakage of control set was significantly

higher than that of SA-treated fruits. Therefore, these results indicate that SA can maintain membrane consistency through enhancing the antioxidant potential of the plant. Reduction of electrolyte leakage and prevention of oxidative damage to cells under stress conditions has been mentioned as primary mechanisms of stress tolerance. The same results were obtained from postharvest treatment with SA to prevent chilling injury (Sayyari *et al.*, 2009; Soleimani Aghdam *et al.*, 2012) and electrolyte leakage (Sayyari *et al.*, 2009; Soleimani Aghdam *et al.*, 2012; Orabi *et al.*, 2015).

Fruits with SA treatments showed lower levels of decay as compared to that of the fruits of control set and in pre and postharvest treatments 4+4 mM, there were not any decay symptoms in tomato fruit after 40th days. Salicylates are major components of the signal transduction pathways of plants playing an important role in disease resistance (Asghari and Soleimani Aghdam, 2010). Different researches show that SA had no direct effect on the decrease of decay in pear fruits (fruits were sprayed with SA), but it might reduce fungus development (Shafiee *et al.*, 2010). Babalar *et al.* (2007) reported SA in a concentration dependent manner from 1 to 2 mM effectively reduced fungal decay in Selva strawberry fruit. Salicylic acid applied to either plant's vegetative stage, fruit development stages or postharvest stage could completely control decay and increased fruit shelf life. Yao and Tian (2005) showed preharvest and postharvest treatments of sweet cherry fruit with SA showed significantly lower disease percentages in storage at 25°C than the control. At 0°C, the inhibitory effects of preharvest SA treatments on postharvest disease were better than those of the postharvest treatment. Shafiee *et al.* (2010) also obtained similar results for pre and postharvest SA treatments on strawberry fruit.

Tomato fruits vitamin C content was decreased during storage and fruits treated with SA showed comparatively higher levels of ascorbic acid than the fruits of control set. Shahkoomahally and Ramezanian (2014) reported that the utilization of ascorbic acid during later storage periods may be the reason for its decreased amounts. Generally, when fruits become overripe, vitamin C content declines concurrently with the degradation of fruit tissues. The results obtained from this study indicate that the SA treatments were beneficial in delaying degradation of ascorbic acid content during storage. Therefore, The SA treated fruits exhibited higher maintenance of ascorbic acid as compared to that of control set. SA prevents vitamin C destruction by increasing the antioxidant ability and resistant of plants and fruits (Wang *et al.*, 2006; Shafiee *et al.*, 2010). Also, exogenous SA could be effective in reducing the rate of respiration and ethylene production (Renhua *et al.*, 2008). Thus, the results of this study confirm previous reports of postharvest treatment with SA to preserve vitamin C content in tomato (Pila *et al.*, 2010), orange (Huang *et al.*, 2008), rambutan fruit (Supapvanich, 2015) and pineapple fruit (Lu *et al.*, 2011).

Titratable acidity content in treated fruits was higher than the control set. Titratable acid depends directly on the concentration of organic acids in the fruit as an important factor in maintaining the quality of fruits (Kazemi *et al.*, 2011). Therefore, any treatment that slows the metabolism and aging of the product can slow down the changes during storage to reduce titratable acid (Zokaee Khosroshahi *et al.*, 2007). A correlation between enhanced respiration and a decrease in TA has been suggested by Shahkoomahally and Ramezanian (2014) to be due to the use of organic acids as respiratory substrates in the respiratory cycle in fruits. Organic acids have a higher ratio of oxygen to carbon compared to carbohydrates or fatty acids; therefore, those are easier to consume as an energy source in the process of respiration. Salicylic acid reduces respiration and ethylene production, leading to the reduction in consumption of organic acids as respiratory substrates (Serrano *et al.*, 2003). Salicylic acid application in this experiment had a significant effect on soluble solids. Therefore, soluble solids of control fruits were higher than of treated fruits. Bal and Celik (2010) revealed that after harvest and during storage and ripening of the fruits was increased the TSS content. Asghari and Soleimani Aghdam (2010) and Bal and Celik (2010) reported that cell walls contain large amounts of polysaccharides, mainly pectins and cellulose, and are digested due to the activity of the cell wall degrading enzymes leading to a significant increase in TSS content. Salicylic acid effectively protects cell walls by decreasing the expression of degrading enzymes and as a consequence prevents from dramatic increase in TSS content of the cells, and caused slow down of ripening. Similar observation was reported with SA treated banana. Salicylic acid treatments inhibited ethylene biosynthesis and delayed the senescence. This is because in the control fruits, due to the aging process (ripening), cell wall was digested and increased soluble solids. On the other hand, SA treatment reduces cellular metabolic activities, such as

respiration and ethylene production, and thus maintains the membranes and cell walls, and prevents from an abnormal increase in the soluble solids (Valero *et al.*, 2006). An increase in TSS content of fruits during storage due to the conversion of starch to be soluble sugars is one of the ripening indexes (Fisk, 2006). This result was in agreement with Babalar *et al.* (2007) who reported that the use of salicylic acid decrease TSS of strawberry fruits and consequently, effectively delays fruit senescence process. Treatment of kiwifruits maintained a lower TSS content than the control fruits at the end of cold storage (Soleimani Aghdam *et al.*, 2009). However, it is in disagreement with Lu *et al.* (2011) results on pineapple fruit and Shafiee *et al.* (2010), report on strawberry, who suggested that SA did not affect soluble solids content and titratable acidity.

The activity of APX in treated fruits was higher than the controls. The study indicated the beneficial effects of SA by pre and postharvest treatments on tomato fruit quality. Wang *et al.* (2006) and Soleimani Aghdam *et al.* (2012) reported that SA might mitigate postharvest CI in fruits and vegetables via different mechanisms. These mechanisms include: a) enhanced alternative oxidase (AOX) gene expression as an efficient ROS avoidance gene, b) increased ascorbate peroxidase (APX) and glutathione reductase (GR) activity, c) enhanced reduced-to-oxidized ascorbate (AsA/DHAsA) and reduced-to-oxidized glutathione ratios (GSH/GSSG) and d) improved heat shock proteins (HSPs) gene expression in peach fruits. Orabi *et al.* (2015) suggested that there is an important link between plant antioxidant ability and the applied doses of the SA. The observed variation (increase) activity of APX is due to SA activates the resistance system and increases the cell antioxidant capacity. Asadi *et al.* (2013) showed that exogenous application of salicylic acid lightened the toxic actions induced by stress and decreased lipid peroxidation rates with increasing antioxidant activity. There is not any report on the effects of pre and postharvest treatments with SA on fruits APX activity.

As a whole, this study showed that pre and postharvest treatments of SA are an effective method of extending storability and postharvest life of tomato fruits at 10°C. The most effective treatment in reducing losses of fruit quality was found to be SA 4+4mM treatments during the storage period of tomato fruit. It was determined that under these conditions Baraka tomato could be stored for 40 days without losing much of its quality.

Acknowledgements

Financial support for this work was provided by Vice chancellor of Faculty of Agriculture and Natural Resources of Hormozgan University.

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